CHAPTER 5
RESIDENTIAL AND COMMERCIAL SECTORS

5.1 INTRODUCTION

Energy use in the residential and commercial sectors primarily results from activities that take place in homes and other buildings. Although the two sectors consist of different classes of buildings having different types of equipment, they are both affected by the same general kinds of mitigation options. A similar analytical approach may be used for both sectors, but its application must take into consideration the different features and dynamics of each sector.

An important feature of the residential sector in developing countries is the growth that is taking place in the demand for energy services. In the industrialized countries, demands for many energy services have become saturated. Growth in population will increase total service demand, but usage per household will not increase dramatically even if incomes rise. For example, the number of refrigerators per household and the amount of volume per household cooled by refrigerators in U.S. residences is unlikely to grow much over the next twenty years. In developing nations, where many people are just now beginning to acquire refrigerators, the demand for the service delivered by refrigerators is increasing rapidly.

5.2 MITIGATION OPTIONS

Mitigation technology options for the residential and commercial sectors may be grouped into four broad categories: (1) efficiency improvements on existing and new building shells, (2) efficiency improvements on new equipment, (3) efficiency improvements on existing equipment, and (4) switching to energy sources/equipment with lower GHG emissions. Within each of these categories, there are a variety of technologies and practices that may be applied to reduce energy use or switch to energy sources with lower GHG emissions. For an overview of energy-efficient technologies for buildings, see Koomey *et al.* (1994) or OTA (1992).

It is important to recognize that individual technologies in buildings often interact. For example, measures that reduce energy use for lighting in commercial buildings also reduce air conditioning requirements, but may increase space heating requirements, depending on the climate. The interaction among measures also means that the energy savings associated with one technology cannot be assessed in isolation from other technologies with which it interacts.

5.2.1 Efficiency Improvements for Existing and New Building Shells

A variety of measures are available for making both existing and new building shells more energy-efficient. These include use of adequate levels of insulation for ceilings, walls, and floors; insulating glazing for windows; control of air infiltration; shading devices or solar control glazing to reduce unwanted solar heat gains through windows; and high-albedo materials, coatings, and paints to reflect shortwave solar radiation and thereby keep building surfaces cooler.[1]

Such measures may affect energy consumption for space heating and/or cooling. Measures can generally be applied more easily and at lower cost in design and construction of new buildings, but

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[1] Use of high-albedo materials, coatings, and paints can also help keep urban surfaces cooler and thereby keep the urban air temperature from rising (the so-called "urban heat island effect"). Along with tree planting, this measure can reduce energy use for cooling. The size of the impact depends on the local climate and the nature of the urban environment.

considerable reduction in energy use can also be attained via retrofit of existing buildings. The cost-effectiveness of different types of improvements depends heavily on the climate in which a building is located and whether energy is used for both heating and cooling or for only one of the two.

A companion strategy for reducing the need for mechanical heating and cooling is to make effective use of natural heating and cooling. Design techniques include passive solar design, which seeks to utilize energy from the sun by proper placement of windows and incorporation of thermal storage; use of natural ventilation for cooling, such as practiced in much traditional architecture; and planting of trees to block the sun or wind.

5.2.2 Efficiency Improvements for New Equipment

Efficiency improvements on new equipment include both incremental changes to a type of equipment and use of different technology that is more efficient than the technology which it replaces. Examples of the former are increasing insulation in refrigerators and using a more efficient compressor in air conditioners. Various design measures can be applied to any type of equipment to improve its energy efficiency. In the residential sector, the most significant types of equipment are refrigerators, water heaters, and depending on the climate, space heaters and air conditioners.

Cookstoves using biofuels are also important energy users in many developing countries, and various improved designs are available either commercially or as prototypes. The magnitude of net CO_2 emissions from biofuels consumption (i.e., the amount that is harvested on a non-sustainable basis) in any given country is uncertain. For this reason, the IPCC Draft Guidelines for National Greenhouse Gas Inventories requires that net CO_2 emissions from burning of biomass fuels be treated as zero (IPCC/OECD, 1994). Thus, measures that improve the efficiency of biomass use do not affect CO_2 emissions from the residential sector. Rather, they increase biomass stocks. Therefore, options to increase the efficiency of biomass use are discussed under Forestry.

Combustion of biofuels also results in emissions of other GHGs, such as methane, CO, N_2O, and NO_X. The global warming potential of these products of incomplete combustion can be considerable, depending on the time scale chosen and whether indirect warming effects are included. If possible, these gases should be accounted for in a GHG inventory. Measures affecting the efficiency of biofuels use will often result in reduced emissions of these gases.

The full cost-benefit analysis of biomass end-use efficiency options should include the reduced emissions of non-CO_2 gases, the gain in biomass stocks (which should be accounted for under Forestry), as well as the economic and health benefits to the end users.

Examples of use of different technology that is more efficient include compact fluorescent lamps, heat-pump space or water heaters, electronic fluorescent ballasts, and high-pressure sodium lamps for outdoor lighting. All of the above technologies are commercially available, but may not be readily available in all countries.

5.2.3 Efficiency Improvements for Existing Equipment

Efficiency improvements on existing equipment include both physical improvements to equipment to enhance its performance and improved utilization of equipment. Examples of the former are heating equipment tune-up, insulation of heat distribution systems, and use of adjustable-speed drives on motor-driven equipment. Examples of improved equipment utilization include use of energy management systems, which are computerized control systems that can be programmed to operate building lighting and

HVAC equipment, and the use of automated lighting controls, which allow more efficient management of lighting energy use in commercial buildings. Manual controls that allow occupants to use equipment more efficiently can also provide significant energy savings in space heating and cooling.

5.2.4 Switching to Energy Sources/Equipment with Lower GHG Emissions

Options for switching to energy sources/equipment with lower GHG emissions include substituting solar for conventional water heaters, substituting electric for kerosene lamps, substituting biogas for other biofuel stoves, and substituting gas for coal in space heating. In many cases, the new equipment is more energy-efficient, and the new energy source has lower carbon content per unit of energy.

The use of substitute energy sources depends on their availability. In some cases, construction of energy supply infrastructure may be required (e.g., rural electrification, gas distribution network). The GHG impact of switching to electricity depends of course on the energy mix for electricity generation, and thus cannot be fully analyzed prior to conducting an electricity demand/supply integration.

In some circumstances, substituting kerosene or LPG for biofuel cookstoves may yield a reduction in GHG emissions and an increase in biomass stocks. Although kerosene and LPG are fossil fuels containing carbon, stoves using kerosene and LPG are several times more energy-efficient than typical biofuel cookstoves and have much fewer emissions of non-carbon products of incomplete combustion such as methane. A disadvantage of this option is that the petroleum products may need to be imported, while biofuels could be sustainably produced in most countries.

5.2.5 Screening Options

The applicability of different mitigation options varies among countries more in the residential and commercial sectors than in others. Options affecting space heating are not of much interest in most developing countries, while options affecting air conditioning are of low interest in the transition countries. Similarly, options affecting biomass use are not very important in the transition countries, but are of interest in many developing countries.

The general criteria for screening options are described in Chapter 2. Below we discuss several criteria that are particularly important in screening options for the residential and commercial sectors.

Size and growth rate of end use. It is important first to identify which end uses are the largest and/or the fastest growing consumers of primary energy and to target those end uses for further analysis. Surveys of equipment ownership and sales are helpful in this endeavor as are measured data on energy use of particular equipment or buildings.

New vs. existing buildings. Buildings typically have lifetimes of 50 to 100 years. In most developed nations, the annual growth rate in building stocks is relatively modest (typically 1-3%/year), which (along with the relatively long lifetime of buildings) implies that achieving significant energy savings requires retrofitting existing buildings. Such retrofits are typically more difficult and expensive than building a more efficient building in the first place. Developing nations usually have rapidly growing building stocks so programs to affect existing buildings should have a lower priority than programs and policies that target new buildings.

High cost-effective savings potential. Once the largest and fastest growing end uses are identified, one can estimate which end uses have large and cost-effective savings potentials (based on previous studies or expert judgment). Combustion-related processes are limited by the First Law of

Thermodynamics to less than 100% efficiency, while other processes that do not depend on combustion (e.g., heat pumps, cooling, and lighting) can achieve much higher efficiencies. In residential buildings, large cost-effective savings potentials are typically found in lighting, water heating, refrigeration, and space conditioning. In the commercial sector, cost-effective savings in lighting and cooling are usually large.

Ease of affecting market choices. Another important issue in screening options is the ease of changing the market to induce manufacturers to produce and consumers to purchase more efficient equipment. It is always easier to affect the efficiency of manufactured devices (such as appliances) than to affect that of site-built structures (such as most residential and commercial building shells). The quality control issues are less difficult for manufactured devices, and the number of supply-side actors to be affected by policy is usually smaller than for site-built structures. This criterion argues that for rapid short-term benefits, a focus on appliances and equipment is appropriate. It will take longer to implement standards and other policies for site-built building shells, but they are no less important in the longer term because of the long lifetime of buildings.

5.3 INPUTS FOR RESIDENTIAL AND COMMERCIAL SECTOR ANALYSIS

An analysis initially requires data on total consumption of each energy type by the residential and commercial sectors in the base year. In many countries, the division of oil, district heat, or biomass consumption between the residential and commercial sectors must be estimated. If such a disaggregation has not been done as part of the GHG Inventory, it should be estimated for mitigation analysis. In this case, analysis of options affecting these energy sources will be approximate.

A common approach for analysis of residential and commercial energy use involves disaggregating energy consumption by end uses such as space heating and cooling, cooking, lighting, refrigeration, and others. In industrial countries, analysis of technology options for specific end uses has been supported by extensive surveying by governments and utilities. The end-use approach has also been applied in developing countries for residential analysis,[2] but in many cases data are not sufficiently detailed for this approach to be used. End-use analysis of the commercial sector is particularly difficult due to the variety of building types in the sector and the general lack of survey data.

The structure of the analysis in each sector will depend on the end-use disaggregation that is chosen. For each end use considered, the minimum required inputs for scenarios are data on (1) the relevant variables that drive the demand for energy, and (2) fuel and electricity intensity.

For many end uses, the number of devices is used as a “driving” variable. For space heating, one might use floor area. For the commercial sector, where end-use analysis is more difficult, one can use total floor area (if data are available) or total valued added.

In many developing countries, it is important to distinguish between urban and rural households because the characteristics of households and buildings in these two areas can be very different. In these cases, separate analyses should be done for urban and rural households. This requires a disaggregation of energy consumption and equipment stocks in the base year into urban and rural components.

[2] Examples include India (Asian Development Bank, 1993), Mexico (Masera *et al*., 1993), and Venezuela (Figueroa *et al*., 1992).

Energy consumption in the base year by end use. The degree of disaggregation depends on the available data. One might choose to estimate energy consumption in the two or three most important end uses and place the remainder of energy use in an "other" category. For the commercial sector, for which end-use data are often difficult to estimate, one might choose to do a very simple end-use breakdown, such as dividing electricity consumption into lighting and "other," and considering all fuel use at an aggregate level.

If information on energy consumption by end use is not available from an authoritative source, then estimates must be made. Sometimes previous estimates made for countries with similar characteristics can be adopted to approximate the energy consumption by end use in the country under study. In the longer term, surveys should be done and measurements taken of who has what kind of equipment and how much energy is used by particular types of equipment. The results of these surveys and measurements can then be used to more accurately characterize the base year energy consumption by end-use.

Data on building/equipment stocks for each end use studied. Data on the saturation of end-use devices (e.g., refrigerators, cook stoves) may be obtained from surveys. For space conditioning end uses, it is desirable to disaggregate the building stock into appropriate categories (such as detached houses and apartments). Similarly, for certain types of equipment, one may choose to keep separate account for sub-categories (e.g., small and large refrigerators).

Basic sectoral "drivers." The basic drivers are the number of households for the residential sector and total floor area or value added for the commercial sector.[3] Projections of the future number of households often may be obtained from official sources. Projections of commercial-sector floor area may be based on growth in commercial-sector value added, which should be obtained from the macro-economic forecast used for the country study.

Future equipment stock for each end use studied. For the residential sector, the usual approach is to project a future saturation of each type of equipment, which refers to the percentage of households having the equipment. The future saturation should be related to growth in household income; its estimation may be assisted by comparisons with other countries. For the commercial sector, one can use a rate of growth in the number of devices in a given end use. This rate may be based on the projected growth in floor area or value added.

Technology data. The basic steps for characterizing technical options for the residential and commercial sectors are as follows (adapted from Krause *et al*., 1987):

- Identify the types of technologies currently in place, their average lifetimes, energy efficiency, and utilization. The degree of detail can vary considerably, from using one type/size of technology as a proxy for an entire class to developing data on many types/sizes.

- Create an inventory of energy-efficient technologies or technical improvements and characterize their energy savings relative to current

[3] Value added is not a very desirable indicator to use because it is often not accurately measured and it is shaped by the changing structure of the commercial sector. However, one has no viable alternative if data on floor area are lacking (which is often the case).

average technology. One can complement this inventory with advanced engineering options for further improving the energy efficiency of the best commercially available equipment.

- Assemble data on the current market prices and projected price developments for efficiency technologies or technical improvements. In considering the societal perspective, prices should be net of import duties and other taxes.

Technology characterizations for a number of important energy-efficiency technologies for the buildings sector are described in detail by Koomey *et al*. (1994).

The savings potential of a measure is typically based on engineering calculations (backed up by measured data on energy savings, in the best case) relative to a baseline technology. For space conditioning measures, these calculations typically use a building simulation computer program to estimate heating and cooling energy use in a given climate with a particular building (or an average building, known as a prototype). For other end uses, simple engineering calculations or data from equipment testing (for new equipment) usually suffice. These calculations usually compare the best currently available technology with the baseline technology.

To produce consistent economic comparisons, the analyst must make certain that the level of service delivered by efficient devices is at least equivalent to that of the devices they replace. Costs can be based on current market prices or on engineering estimates (for near-commercial technologies). Care must be used in adopting market prices because costs of efficient technology in the current market may be higher than the costs that would prevail if the market for the efficient technology grows considerably.

5.3.1 Issues in Analysis

Treating measure interactions. To properly estimate the energy savings potential of conservation measures, they should be ranked in order of increasing cost per GJ or kWh saved (the cost of conserved energy, or CCE). Determining this order is simple for efficiency measures that are independent. However, the ranking becomes complex when the energy saved by one conservation measure depends on the efficiency measures that have been implemented previously.

Consider conservation measures applied to a residential water heating system. The energy savings attributed to certain improvements in the water heater's efficiency will depend on the amount of hot water demanded, which will depend on the measures that may have already been implemented (such as low-flow showerheads). The sum of savings of each measure implemented alone will be greater than the two implemented together. If the interdependence of the measures is not taken into account, it is possible to "double-count" the energy savings.

A properly calculated efficiency potential will avoid double-counting errors by using the following procedure:

The CCE is calculated for each of the interacting measures.

The least expensive (i.e., lowest CCE) measure is selected and "implemented"; that is, the energy savings from the first measure are subtracted from the baseline energy use.

The new energy use is used to recalculate the CCEs of the remaining measures. (In general, their CCEs will rise.)

The measure with the next lowest CCE is selected and implemented.

The energy savings of the remaining measures are recalculated and the measures are re-ranked. This procedure is repeated until all the interacting measures have been ranked.

An important consideration when analyzing commercial lighting technologies is the interaction between heating, ventilation, and air conditioning (HVAC) and lighting energy use. Reducing lighting energy will decrease cooling energy use and increase heating energy use because the waste heat from the lights will be reduced when more efficient equipment is installed. In hot climates, this effect always leads to additional energy and cost savings. The exact size of the additional savings depends on particular building characteristics and weather patterns. These interactions can be treated by simulating the effect of lighting energy savings on HVAC energy use with a building energy simulation model (Sezgen and Huang, 1994).

Accounting for side benefits. Many efficient technologies provide better services than those they replace. It is important to account for these additional benefits because in some cases they can be more important than the direct value of the energy saved. An example of the importance of side benefits is that of using electric lighting as a substitute for kerosene lighting in rural homes. The gain in service (lighting quality) is generally more important than the energy savings involved. In the commercial sector, efficiency technologies may also improve worker productivity and should be allocated that benefit.

Avoided costs from efficiency measures. To assess the cost-effectiveness of a mitigation option, one can compare the CCE to the avoided supply cost. One typically uses an average avoided cost. In reality, the avoided cost will vary depending on the impact of the conservation measure on the daily electricity load and the characteristics of the utility system in which the savings accrue. For example, refrigerator savings are baseload in character, occurring throughout the year at a relatively constant rate. Lighting savings are more likely to accrue at times when the utility system is faced with meeting peak demand; avoided costs will generally be higher in this case. For discussion of how to treat peak demand savings from efficiency options, see Koomey *et al.* (1990).

5.4 DEVELOPING RESIDENTIAL AND COMMERCIAL SECTOR SCENARIOS

5.4.1 A Basic End-Use Accounting Framework

This section describes a simple procedure for developing scenarios for particular end uses. For each end use selected, one projects the future evolution of equipment stocks and analyzes particular technology options for meeting future energy service demands. Since different options may be targeted at existing and new equipment or buildings, it is necessary to keep separate account of these two classes. In this method, one estimates the total number of devices (or buildings) in the target year and estimates a retirement rate for existing equipment (or buildings), which leaves a certain number surviving in the target year. The number of new devices (or buildings) that entered the stock over the study period is simply the difference between these two quantities. Efficiency measures are then applied to either existing or new buildings or equipment as appropriate.

The end uses of residential refrigeration and commercial lighting are taken as examples. In these examples, there are only two types of equipment for each end use: standard and energy-efficient. In a more sophisticated analysis, one would use more than two types.

The required inputs are an estimate of total energy consumption in the base year for the end use, a projection of equipment stocks, and average energy intensities of existing and new equipment (or buildings). In the example presented in Table 5-1, all values are expressed as indices, where the base-year (1995) value is equal to one. An analyst could use actual values rather than indices.

Step 1. Estimate the shares of base-year surviving equipment (or buildings) and new equipment (or buildings) in the future stock. To estimate a retirement rate for existing buildings or equipment, information is required on lifetimes.[4] The stock of devices (or buildings) still existing in the target year can be expressed as a fraction of the base-year stock. In the example, we assume that the total number of refrigerators grows as a function of the growth in households and in refrigerator ownership per household (saturation), while the total number of lighting fixtures in the commercial sector grows as a function of the growth in floor area and saturation (equipment per unit of floor area). The stock of new devices installed after 1995 (expressed as a fraction of the base-year stock) is simply the difference between the total stock in 2015 and the stock of devices existing in 1995 that survive to 2015.

Step 2. Use energy intensities of existing and new equipment (or buildings) to derive a baseline scenario of energy use. One can express the energy intensity of new devices as a fraction of the base-year intensities for existing devices. As illustrated in the example, the average intensity of new equipment is often lower than that of existing equipment.

In a "frozen efficiency" baseline, the intensity factors are assumed to remain constant throughout the forecast (both existing and new devices are frozen at their 1995 intensities, but new devices replace existing devices as they retire). One calculates electricity use for surviving devices by multiplying the stock of surviving equipment by the intensity of such devices and by the total energy consumption for that end use in the base year. One then multiplies the stock of new devices by the intensity of such devices and by the total electricity use in the base year, and adds the results of this and the previous calculation. This assumes that all new devices are of the standard type.

To develop a "likely trends" baseline, one must make assumptions about how intensities are likely to change because of market forces over the forecast period. The simplest approach is to assume that some share of new devices are of the efficient type (see below) rather than the average type. A more advanced approach would consider different degrees of efficiency improvement that might occur.

Equipment in buildings is usually not retrofitted (instead it is replaced at the end of its useful life) so that the assumption that surviving equipment remains at fixed intensities until retired is probably accurate. Building shells are often retrofitted due to their long lifetimes. Thus, the intensity factors for space conditioning end uses affected by shell retrofits must be adjusted to reflect such retrofits. The "frozen efficiency" baseline assumes no retrofits occur, whereas the "likely trends" baseline may assume that some of the stock receives retrofits.

Step 3. Use energy intensities of efficient technologies to derive the technical potential for energy savings. Energy use is calculated in the same manner as for the frozen efficiency case except that all new devices are assumed to be of the efficient type. If shell retrofits are being considered, one assumes that all surviving buildings receive the retrofit by the target year. The energy intensity of efficient technologies is based on the engineering calculations described earlier

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[4] A common assumption is that devices retire at an exponential rate equal to the inverse of the device lifetime. Other retirement assumptions may be more accurate in particular circumstances.

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5.4.2 Detailed Equipment Stock Models

The most accurate way to assess efficiency potentials in a bottom-up analysis is to begin at the lowest level of disaggregation that the data allow. For buildings, such analysis involves creating building prototypes with thermal and equipment characteristics corresponding to new and average existing buildings. These prototypes are then run through a building energy simulation program with average weather to estimate heating and cooling energy use for different insulation levels and equipment efficiencies. For appliances, energy use is determined from engineering simulations and measured data. This detailed approach is exemplified by the work of Krause *et al*. (1987) and Koomey *et al.* (1991). These methods require data that can be difficult to obtain so assumptions are often required.

Equipment stocks. In a more detailed approach, the stock of relevant equipment is typically tracked at the level of technology, vintage (year of entry into the stock), and fuel. For example, Koomey *et al*. (1993a) describes a residential forecasting model that keeps track of stocks and other information for about a dozen different classes of refrigerators with each class allowed to choose from ten or more technologies. These stocks are inferred from industry sales data or anecdotal evidence. Building shell stocks differ by region, vintage, and space-conditioning equipment type, and in the best case these stocks are tracked at this level of detail.

The differing lifetimes of building shells and equipment are used to estimate retirement rates and to group the building stock into different categories that are tracked explicitly. For example, buildings existing in the base year and still existing in a forecast year would be split into those with original equipment and those with equipment that has been replaced since the base year. The number of buildings in the first category would decline at a rate determined by the retirement rate of the equipment as well as the retirement rate of building shells. The number of buildings in the second category would increase over the duration of most forecasts even though the total number of base-year buildings still existing in a forecast year would decrease over time.

Energy intensity and efficiency factors. Intensity factors are not usually used in the more detailed calculations. Instead, each technology is assigned an energy consumption per unit (UEC, in kWh or GJ/unit/yr), based on engineering calculations or measured data. The unit energy consumption is a function of equipment efficiency and usage behavior and these two parameters are specified independently in the most sophisticated end-use models.

In a frozen efficiency scenario, the energy use per unit and the equipment stocks are tracked at the technology level. Total energy use in the base year is equal to the stock of equipment in that year times the average UEC for that equipment. For some devices, the capacity of the device (e.g., installed wattage for lighting) is also treated separately. The frozen efficiency forecast is created using the same conventions as before except the energy use of typical base-year existing and new devices is specified in greater detail. The forecast of equipment stocks must also be disaggregated to the technology level, which makes such forecasts data-intensive and computationally demanding.

To estimate a business-as-usual baseline scenario, bottom-up forecasting models typically use some form of life-cycle cost calculation and diffusion curve to estimate the rate of penetration of new technology. The rate of such penetration depends on fuel prices, capital costs, logistic constraints, and other considerations.

Estimating technical potential. Examples of a more detailed approach are two studies that assessed conservation potentials for residential refrigerators and commercial lighting.

A detailed study of refrigerator efficiency options was conducted in the U.S. to determine the level at which minimum efficiency standards for refrigerators should be set (US DOE, 1989a). The analysis relies on an end-use forecasting model that characterizes refrigerator energy use and associated capital costs by class of refrigerator (e.g., automatic defrost with top-mounted freezer, manual defrost, etc.) and by technology type. The energy-savings estimates are based on engineering calculations using an established methodology. Since refrigerator usage does not vary much, these engineering calculations can give a very accurate picture of energy use for refrigerators under average conditions. The study creates a business-as-usual forecast and then assesses the potential impacts of different efficiency standard levels in terms of energy use, costs, and shipments of different technologies and classes of refrigerators.

A detailed assessment of lighting efficiency potential is that of Atkinson *et al*. (1992). This study tracks equipment stocks at the level of technology and assesses the potential impacts of standards, incentives, and information policies on residential and commercial lighting energy use. Incandescent lamps as well as fluorescent fixtures, lamps, ballasts, and controls are treated in detail. Both current and advanced technologies are analyzed. Energy use is estimated using a bottom-up approach that relies on installed wattage, efficiency data, and usage data by technology and building type (e.g., offices, retail, restaurants, etc.). Both frozen efficiency and business-as-usual cases are presented.

5.4.3 Simple Scenario Development

This method provides a baseline scenario of energy use and a rough characterization of the potential for reducing energy use in end uses for which specific mitigation options are not analyzed. One estimates future fuel and/or electricity intensity for each of such end uses for a baseline and a mitigation scenario.[5] General knowledge of how energy is used allows a rough assessment of the likely trends. This approach relies on both consideration of historic trends and expert judgment as to how a particular end use could evolve.

The mitigation scenario represents a rough estimate of the total fuel and electricity savings that could result from a set of mitigation options. This analysis does not consider specific mitigation options. Costs of a mitigation scenario are very difficult to estimate with this method.

Project fuel and/or electricity intensities in each end use for a baseline scenario, and calculate total consumption of each energy type. Projecting future energy intensities in a "likely trends" scenario requires combining historical data with judgment about the future. For example, one might assume that average energy use per household for lighting

[5] Alternately, several end uses may be grouped into a single category. For example, one might group all commercial-sector electrical end uses into a single category. Estimating changes in a category that comprises several different end uses is difficult, however.

will increase from 100 kWh/year to 200 kWh/year due to increases in size of homes and in the number of lighting sockets.

Another approach is to estimate future intensities by reference to current intensities in other countries. One makes a judgment that the end use in the study country is likely to reach the intensity level of some other country by the target year. For example, one might assume that the average lighting energy intensity in the study country will reach the current level of Japan or Spain by the target year.

If many end uses are grouped in an "other" category, the change in intensity can only be estimated very roughly. For example, if one is considering total fuel use per unit floor area in the commercial sector, one might estimate that there will be a moderate increase in intensity due to higher demand for energy services such as heating or water heating.

Multiplying the intensity by the number of devices, households, or amount of floor area yields total energy consumption for each end use.

Project fuel and electricity intensities in each end use for a mitigation scenario, and calculate total consumption of each energy type. The possible approaches are similar to those for projecting baseline scenario intensities except that in this case one considers changes that could occur if efficient technologies were widely adopted. If one is using actual intensities in other countries to estimate what the intensities in the study country could be, one should select a country whose residential sector or commercial sector is similar to what the same sector in the study country could be in the target year if policies encouraged efficiency improvement.

5.5 MITIGATION POLICIES

Policies affecting energy efficiency in the residential and commercial sectors fall into four basic categories: efficiency standards, incentive programs, information programs, and market transformation programs (chiefly government purchasing).

5.5.1 Minimum Efficiency Standards

Minimum efficiency standards may apply to appliances and other equipment and to new buildings or those undergoing substantial renovations. Efficiency standards can take two forms: prescriptive standards, which mandate specific technologies, and performance standards, which mandate a specific level of energy consumption. A standard can also give the user a choice of prescriptive or performance approaches.

Standards for new buildings exist in many countries throughout the world, but are often not very stringent with respect to energy efficiency (Janda and Busch, 1994). In addition, building standards are often enforced by local officials who are understaffed and insufficiently trained (Usibelli and Stevens, 1988).

A different type of standard for new buildings involves electric utilities establishing minimum efficiency requirements for new buildings hooking up to the system (Bellamy and Fey 1988). Utility service standards have been used extensively in the Northwest U.S. (Vine 1986). They have been successful in part because they apply leverage to the builder/developer at a key point in the development process. Such policies can be effective in countries where on-site enforcement may be difficult.

Because of concentration in the appliance industry and because mass-produced devices are easier to change than site-built devices, equipment standards are more effectively enforced than are building standards. Appliance standards have been popular in the U.S. (McMahon *et al*., 1990), and are being considered in Western Europe. The data collected for the U.S. appliance standards rulemakings is extensive and has proved valuable for analysts both within and outside the U.S. (US DOE 1988, US DOE 1989a, US DOE 1989b, US DOE 1990, US DOE 1993a, US DOE 1993b, US DOE 1993c) .

By themselves, minimum efficiency standards provide no incentive to produce a more efficient device or building than the standard requires and are often much less stringent than would be cost-effective from society's perspective. They can, however, be combined with incentive programs that will encourage efficiency beyond the standard level.

Voluntary agreements between the government and appliance manufacturers can be an alternative to mandatory standards. Such agreements have been negotiated, with generally positive results, in Western Europe, Japan, and Brazil (Meyers *et al*. 1990). However, these agreements have not pushed the market as strongly as did the appliance standards in the U.S.

5.5.2 Incentive Programs

Incentives usually involve rebates or low-interest loans to those purchasing efficient devices or undertaking building retrofits. Penalties on purchasers of less efficient devices are also possible. In the U.S., rebates have been extensively used by utilities (EPRI 1987a); tax incentives have also been tried, with mixed results. In Western Europe, grants and tax incentives were used in many countries to encourage housing retrofit in the 1970s and 1980s.

Well-conceived financial incentives can influence purchaser decision-making. They may also promote the development of an energy service industry and financial infrastructure needed for continuing success with energy efficiency programs (EPRI, 1987b).

The information component of incentive programs to promote specific efficiency technologies can be important. Utility rebates for compact fluorescent lamps and electronic ballasts deliver institutional credibility to claims that these devices actually save energy. If an architect sees that the utility will pay rebates for installations of ten different devices, search costs have been reduced. The designer can just focus on ways to use those ten technologies in the design without necessarily undertaking a lengthy analysis of all techniques available to reduce energy consumption.

5.5.3 Information Programs

Information programs have been used throughout the world to promote energy conservation in homes and, to a lesser extent, in commercial buildings. Information programs include labeling of devices with efficiency information, utility bill stuffers, booklets listing the most efficient devices, handbooks for building designers, developers, architects and others, and radio and television advertisements. The impact of these programs is difficult to gauge.

Site-specific information may be delivered by energy audit programs. Without incentives or soft loans to encourage adoption of measures identified in audits, however, the rate of adoption is usually low.

The cost of disseminating information can be reduced if the information distribution source is perceived by consumers as being more objective than suppliers, is centralized (it achieves economies of scale in replication and distribution), and it uses existing distribution channels (e.g., utility bills or customer service representatives).

One important means of disseminating information is to conduct demonstration projects using the latest building and appliance efficiency technologies. These projects demonstrate the capability and reliability of new technologies. They can also uncover unanticipated problems in installing these technologies, which can then be corrected before full-scale implementation gets underway.

5.5.4 Government Purchase Programs/Market Transformation

This policy involves governments creating a market for new efficiency technology through their purchasing choices. In this way the efficient technology will be supported in the early stages, which would allow manufacturers to increase production of efficient products and achieve economies of scale more quickly. This policy can be justified on the grounds of direct operating cost-savings to the government, with the added benefit of encouraging more rapid adoption of efficiency technologies in the economy as a whole. Governments could simply mandate technologies for use in new government construction, or they could mandate a certain efficiency or performance level. Government purchase programs of this nature are being implemented at the federal level in the U.S.

5.5.5 Incentives vs. Mandates

Incentives are often preferable to mandates because they allow individual actors to choose the most cost-effective path to achieve the desired level of energy efficiency or emission reductions. Incentives are also more flexible than mandates. Mandates are useful when there are relatively high monitoring costs for incentives or when the required actions are easy, non-controversial, or inexpensive. Properly enforced mandates also may have more predictable effects than incentives although experience gained with early incentive programs can be used to great advantage when predicting the results of future programs. Mandates and incentives should work in tandem, with policy-makers using standards to eliminate the least efficient buildings or appliances and using incentives to promote improvements beyond the level of the mandated standards.

5.5.6 Effectiveness of Policies

Programs are typically only able to capture some fraction of the technical-economic savings potentials described because of real world complexities and limitations. A sophisticated attempt to address these complexities in the context of assessing savings potentials is that of Brown (1993). The results of this work, summarized in Figure 5-1, show that slightly less than half of the technical potential savings identified for the U.S. residential sector (Koomey *et al.*, 1991) can be cost-effectively captured by a combination of appliance standards, building standards, and utility programs over a twenty-year forecast time frame.

Figure 5-1 also shows the individual effect of various corrections to the estimates of energy savings and costs. These corrections each have a noticeable effect, but the biggest effect is that associated with the time necessary to scale up programs and with the imperfect effectiveness of those programs. Program costs, takeback of savings, imperfect persistence of measures, and an adjustment because engineering estimates often overestimate savings all are important correction factors that affect the technical potential. To accurately estimate the achievable potential, one should estimate the effects of all these different factors on an end-use by end-use basis. As this is a difficult process, simple estimates may be made instead.

Cost of Conserved Energy (/kWh)

Figure 5-1 here

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